SPECIMEN PAGES.

ELEMENTARY

PHYSICAL GEOGRAPHY

BY

RALPH S. TARR, B.S., F.G.S.A.

ASSISTANT PROFESSOR OF DYNAMIC GEOLOGY AND PHYSICAL
GEOGRAPHY AT CORNELL UNIVERSITY
AUTHOR OF "ECONOMIC GEOLOGY OF THE UNITED STATES"

New York
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1895

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Take pleasure in announcing that the

Elementary Physical Geography

By

Ralph Stockton Tarr, B.S., F.G.S.A.,

Assistant Professor of Geology and Physical Geography at Cornell University,
Author of "Economic Geology of the United States," etc.,

announced some time since as in preparation, will be ready for publication about the first of October.

Teachers are invited to examine carefully the following sample pages. The complete work will be sent on application without charge to any teacher who wishes to examine it with the expectation of introducing it as a class text-book if found satisfactory. Such applications should state the name of the school with which the writer is connected and the number of copies likely to be ordered in case of introduction.

PLATE 1. — FRONTISPIECE.

Watkins Glen, N.Y. A post-glacial gorge in a shale rock.

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PREFACE.

For some time there have been indications that new text-books on physical geography are demanded; and in the report of the Committee of Ten this finds definite expression. In the preparation of this book, which has been in hand for several years, there is an attempt to meet this apparent demand; but for reasons which are obvious to many, it has not seemed wise to attempt to follow the somewhat radical suggestions which were made by the majority of the geography conference of the Committee of Ten. Therefore, while the physiographic side is given more prominence than is customary in works of this kind, this book attempts to only partly meet the Committee's suggestions.

In the preparation of the book, effort has been made to introduce new material, particularly in the illustrations, which are a prominent part of the book. Also, there has been an endeavor to make the book scientifically accurate, and to introduce the latest knowledge on the subjects treated. There are probably places in which this is not done, for the field is so large that much must be compilation; and the compiler is liable to fall into error.

I anticipate criticism of the order of presentation, of the relative amount of space allotted the various topics, of the omission of some subjects which are usually found in such books, and of the inclusion of some not usually discussed; but these matters have been carefully considered, and the book is the result of a well-matured plan. In many respects it is experimental, but it is a deliberate attempt to supply a book which is certainly needed. It should not be inferred that the author is satisfied with the attempt,—he is keenly disappointed at the constant necessity of saving space and thereby weakening description and explanation. In many cases, explanations have been omitted; in others, perhaps it would have been better to have done so.

It is hoped that the more advanced teachers will find it possible to accompany the text-book work with laboratory and field study, along the line suggested in the appendix. The discussion of method has been systematically eliminated from the text, and the sole effort has been to present facts and furnish information; but if this alone is put before the pupils, the value of the study will be very slight indeed. It furnishes the main story in a connected way, and supplies certain information; but the laboratory and field will supply applications and extensions of the principles, at the same time giving value to the study as a means of mental discipline. Merely to hear recitations from the book, will be the continuation of an all too prevalent habit, which in so many cases makes the science teaching in our secondary schools the weakest part of the curriculum.

While the author has done much work in some of the subjects treated, particularly the ocean and the land, he would not wish to claim that much in the book is original. In reality, this book is based upon the manuscript of another and more advanced work, which is soon to be published as a handbook for teachers and for reference. Both of these represent an attempt to gather from all available sources, the kind of matter which it seemed desirable to include in such books. While in the larger work direct reference is made to the sources of information, it has not seemed desirable to do so in this case; for the acknowledgments take much space and distract the attention, without benefiting the pupil.

I have had much generous assistance in the supply of illustrations, particularly of photographs; and grateful general acknowledgment is made here, while special mention of the sources is made in a list in the succeeding pages. Although I have received aid from many sources, there are a few which I must mention especially. The writings of Geikie, Dutton, Powell, and Gilbert, particularly the latter, have not only given me bodies of fact, but also inspiration, as indeed they have to all who are working in physiographic geology. To the writings and teachings of Professors Shaler and Davis of Harvard University, I owe more than I could possibly acknowledge; and to the latter I am under an added obligation for his examination and kindly criticism of parts of my manuscript. While I acknowledge the debt which I owe these scientists, it must be understood that the mode of presentation is my own, and that I alone am responsible for any shortcomings which may appear.

RALPH S. TARR.

ITHACA, N.Y., August 30, 1895.

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ACKNOWLEDGMENT OF ILLUSTRATIONS.

The following illustrations are from the sources indicated. In some cases they have been exactly reproduced, but in others they have been made more diagrammatic to suit the needs of this book. Some of the illustrations not acknowledged are from photographs or lantern slides, the source of which could not be ascertained.[1]

Abbe, U. S. S. S., Annual Report for 1890, Fig. 56.
Agassiz, Three Cruises of the Blake, Plate 15.
Branner, Journal of Geology, Vol. 1. Fig. 250.
Brown, C. D. (dealer in photographs, Gloucester, Mass.), Figs. 81, 89, 203, 204, and 254.
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Calvin, Prof. S., State Geologist of Iowa, Des Moines, — Photograph by the Survey, Fig. 131.
Canadian Geological Survey, Photograph, Fig. 99.
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Chamberlin, Third Annual Report, U. S. G. S., Fig. 185.
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Gardner, J. L., 2d, Boston, Mass. (Photographs by), Figs. 98, 116,[3] 117,[3] 120, 126,[3] 186,[3] 187, 198,[3] 199,[3] 200, 201, 202,[3] 206, and 255.[3]
Gilbert, Monograph I., U. S. G. S., Figs. 151, 154, 155, 170, 197, and 213; same, Fifth Annual Report U. S. G. S., Figs. 212 and 217; same, Annual Report Smithsonian Institution, 1890, Figs. 166 and 169; same, Geology of the Henry Mountains, Fig. 147.

[1] U. S. C. S., refers to the United States Coast Survey; U. S. G. S., to the United States Geological Survey; and U. S. S. S., to the United States Signal Service.

[2] Some of these which are referred to the Geological Survey publication were made from photographs obtained from the Survey.

[3] Also published by Shaler in Ninth Annual Report, U. S. G. S.

Part I.

THE AIR.

ELEMENTARY PHYSICAL GEOGRAPHY.

CHAPTER I.

THE EARTH AS A PLANET.

Form of the Earth. — The earth is a spherical body composed of three different portions,—a dense central mass, which is probably solid, and two envelopes, the ocean and the air. The central part has a much greater bulk than either of the other portions. In reality the form is not exactly spherical, for the diameter of a sphere should have the same length in all parts; but on the earth the diameter at the equator is 26½ miles longer than that at the poles, where its length is 7899 miles. This flattening of the poles gives to the earth the form of an oblate spheroid instead of a true sphere (Fig. 1).

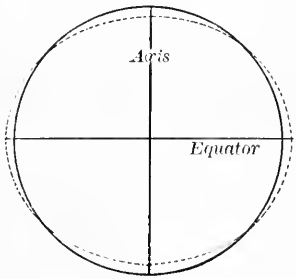

FIG. 1.

Diagram showing a section of a sphere (heavy line), and an oblate spheroid (dotted line).

While this irregularity of the earth was detected only after a series of very careful measurements, it is in reality the greatest on the surface of the earth; but there are other and less extensive irregularities, which are much more noticeable. These are of two kinds, — continents and mountains. The surface rises and falls in a series of great wave-like irregularities, which form the continents and ocean basins. On the continents, and occasionally in the oceans, the surface rises along relatively narrow lines into a series of high mountain ridges. Although these are the greatest elevations on the earth's surface, and therefore attract our attention, they are really very small irregularities when compared with the continents of which they usually form a small portion (Fig. 128).

Considering the sea level as 0, the highest point on the earth is about 29,000 feet in elevation. Depressions of over 25,000 feet are found in several places in the ocean beds. The total range in elevation between the highest mountain, and the greatest ocean depth is about 57,000 feet. It can be readily seen how small this is in comparison with the earth as a whole, when we remember that the diameter of the earth at the equator is 41,847,192 feet. Upon a globe of ordinary size they could not be shown on true scale. Although there are points on the land whose height is greater than the deepest known parts of the ocean, the average depth of the ocean, which is about 12,000 feet, is much greater than the average height of the land, which is approximately 2500 feet (see Chap. XIV.).

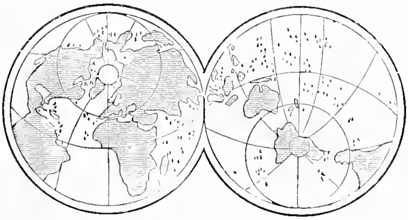

Fig. 2.
Land and water hemispheres.

The greater part of the water on the earth's surface is accumulated in the broad hollows between the continents. The surface of this water mass is much greater in area than that of the land (Fig. 2), the proportion being 1 of land to 2.6 of water (roughly 3:8). Late calculations give the area of the land as 142,000,000 square kilometers, and of the water as 368,000,000 square kilometers. The total volume of the water of the oceans is estimated to be 1,347,874,850 cubic kilometers.

There are other smaller irregularities on the surface of the earth, and many minor peculiarities, some of which are discussed in the later chapters. Surrounding the earth is a gaseous envelope, the atmosphere, which extends to an

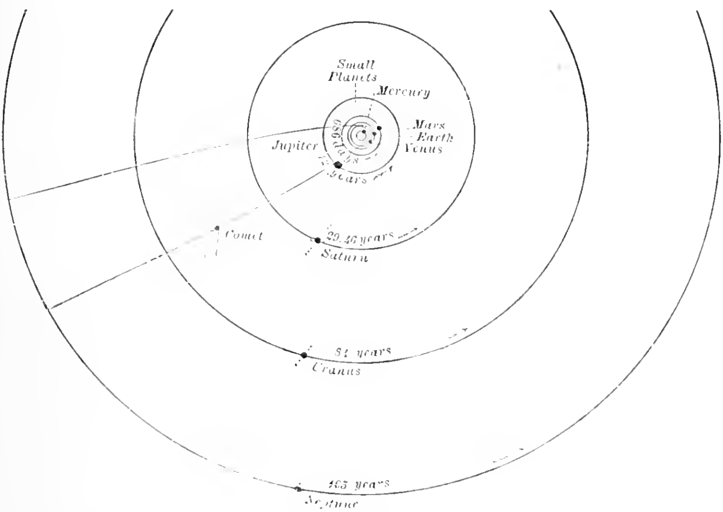

FIG. 3.

The solar system, showing the relative distances from the sun, the direction of revolutions, relative size of the orbits, and the number of satellites.

unknown distance, but which at a height of five or six miles from the surface is very much rarified.

The Solar System.—The earth is one of several bodies which together form the solar system. They are a family of bodies bound together by the tie of gravitation and engaged in a series of movements around a central body, the sun (Fig. 3). In the solar system there are five classes of bodies. In the center is the sun, the largest of all, and the one upon which the others depend more than upon any other member. The second class of bodies is that of the planets, of which eight are known. These all revolve around the sun in orbits which are nearly circular, but not exactly so, being in reality, ellipses with the sun at one of the foci. The third class of bodies is that of the satellites, of which the moon is an example. Most of the planets have satellites, which are always much smaller than the planet about which they revolve. The earth has but one moon, but some of the planets have several. Twenty moons have already been discovered, of which all but three belong to the outer group of planets, Jupiter, Saturn, Uranus, and Neptune. A fourth group of bodies in the solar system is that of the asteroids, of which about 400 are now known. These small planets revolve about the sun in the space between the orbits of Mars and Jupiter. Aside from these members, there is a fifth group of irregular bodies, the comets and meteors, which move in a manner different from that of the other members of the solar system.

The Sun.—The central and largest member of the solar system, the sun itself, unlike the planets, is so constituted that it sends out into space a form of energy which produces both light and heat. It is the source of much of the energy which finds expression upon the surface of the earth in the forms of light, heat, and life itself. This immense body is fully 92,750,000 miles distant from the earth.

Since the sun is able to emit rays which produce heat, we know that it must be a hot body; but there is as yet no means of telling what its temperature is. Owing to the way it effects the movements of the several members of the solar system, it is known that the materials composing the sun are not so dense as the solid part of the earth. It seems quite certain that at least a large part of the sun is in the form of gas. By means of the instrument known as the *spectroscope*, we have learned much concerning the actual composition of the sun. By this instrument it has been found that many of the elements known on the earth exist in the sun in a gaseous form.

Since we know very little about the condition of the earth on which we live, it is hardly to be expected that our knowledge of a body so distant as the sun would be very accurate. Still the studies which have been carried on by means of the telescope have revealed the fact that there are at least three quite different parts to the sun. These are the *corona*, which is outermost, the *chromosphere*, and the *photosphere*, the latter being the densest part. It is the portion from which the light and heat are emitted; and from its surface the diameter of the sun is about 860,000 miles (Fig. 4). Above the photosphere comes the chromosphere, which appears to be the true atmosphere of the sun. It consists mainly of glowing hydrogen gas; but in its lower portions many metals, such as iron, are known to exist in the form of gas. It is in violent commotion, as if in eruption; and the photosphere itself also presents signs of violent activity. Extending to a distance sometimes as great as 300,000 miles above the surface of the sun, is the corona, the character of which is not understood.

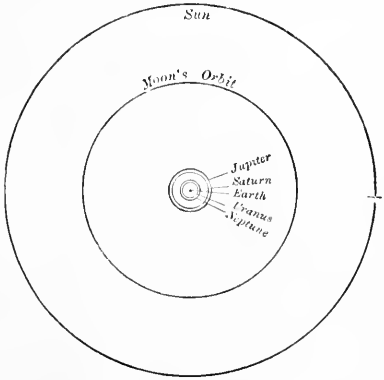

Fig. 4.
Diagram to show the relative size of the sun and the largest planets. Drawn on true scale.

Certain dark bodies known as *sun spots* (Fig. 5) appear upon the surface of the sun and move across its face until they disappear on the opposite side, being carried around by the rotation of the sun. Their origin is not known, but they appear to have an influence upon the earth in at least two ways, one upon atmospheric electricity, the other upon certain climatic features.

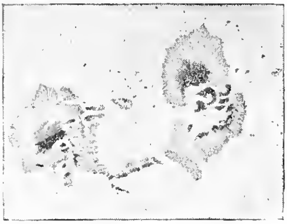

Fig. 5.
Sun spots, 1872.

The sun is engaged in two motions. It rotates, as do all the larger bodies of the solar system; but the period of rotation is not exactly known, though it is somewhere between 25 and 26½ days. Strangely enough, the period of rotation appears to vary according to the latitude. The second motion is one in which the entire solar system is engaged; but the amount and exact nature of this is not known. The system is moving through space at an unknown rate, toward the constellation Hercules.

The Planets.—*Mercury*, the smallest of the planets, is nearest to the sun, on the average being about 35,750,000 miles from it (Fig. 6). The diameter is a little more than one-third

Fig. 6.
Diagram to show the relative distances of the various planets from the sun.

that of the earth (or 2992 miles), and it rotates on its axis in about 24 hours, while it revolves around the sun once in about 88 days. We know little concerning the conditions on this planet.

The next body outside of Mercury is *Venus*, the most brilliant of planets. It is almost the same size as the earth, being in reality about 250 miles less in diameter (7660 miles) (Fig. 7). Some observers think that they have detected a rotation with a period of a little more than 24 hours; but this is doubted by most astronomers. The period of revolution is considerably less than ours, or about 225 days. It appears quite certain that there is an atmosphere upon this planet, and so far as we can tell, it closely resembles ours. No satellite is known to exist.

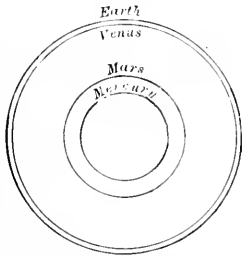

FIG. 7.
Diagram to show the relative size of the smaller planets.

Outside of the earth, which is the next planet in the solar system, comes *Mars*, which next to Mercury, is the smallest of the planets, having a diameter of but little more than 4200 miles. Its time of rotation is a little over 24½ hours, and its revolution about the sun is accomplished in nearly 687 days. Its mean distance from the sun is 141,000,000 miles. The axis of Mars is inclined about 27° to the plane of its orbit, which is about 4° more than the inclination of the earth's axis. There are two tiny satellites, one less than 10 miles in diameter, the other perhaps twice that size; and the latter is not more than 4000 miles from the surface of the planet, about which it revolves in a period of 7 h. 39 m.

Jupiter, the largest of planets (Fig. 4), has a mass greater than that of all the others combined, the mean diameter being about 86,000 miles; but the diameter at the equator is fully 5000 miles greater than that at the poles. The volume of Jupiter is about 1300 times that of the earth. On the average, the distance from the sun is about 480,000,000 miles, and it takes nearly 12 years for it to make a revolution about the sun. The time of rotation is a very little over 9 h. 55 m.

It is evident that what we see with the telescope is not the surface of the planet, but a dense atmosphere of some form of vapor. Therefore we have no means of knowing what the actual condition of Jupiter is, though we may infer that the planet is still heated, and that the clouds which we see are the result of this heated condition. Four moons revolve about Jupiter, the most distant being 1,162,000 miles from the planet, while the nearest is only a little farther away than our moon is from us.

Next beyond Jupiter is *Saturn*, the second largest of the solar planets. Its distance is 881,000,000 miles from the sun, around which it revolves in about 29½ years, while it rotates upon its axis in 10 h. 14 m.[1] This planet has eight moons; but the most remarkable feature connected with it, is its surrounding pair of flattened rings, whose inner diameter is 100,000 miles. The telescope has not yet definitely revealed the nature of these rings.

As the distance from the earth increases, our knowledge of the members of the solar system becomes less accurate. Hence, since its mean distance from the sun is fully 1,771,000,000 miles, *Uranus* is scarcely known. It revolves about the sun once in 84 years, but its period of rotation is not known. There are four satellites.

Until 1846 no other large planet was known; but as a result of prediction, *Neptune* was discovered in that year. The discovery of this planet is one of the most remarkable proofs of the accuracy of the theory of gravitation; for it

[1] It will be noticed that as the distance from the sun increases, the time required for a revolution also increases, while the period of rotation rapidly decreases.

was determined by irregularities in the movement of Uranus, that another planet must exist outside of its orbit; and after careful calculations, the place where this planet could be found was predicted, and Neptune was discovered at a mean distance of 2,775,000,000 miles from the sun. One moon has been detected.

Asteroids.—In the year 1801, a small planet known as Ceres was discovered in the space between Mars and Jupiter. Since that time about 400 other smaller bodies have been found in the same general region. In no cases have these *small planets* a diameter greater than 520 miles, while the smallest that have been discovered have diameters of less than 40 miles. Their movement through space is somewhat irregular; and there have been many speculations concerning their origin, though as yet no satisfactory explanation has been advanced.

The Earth.—While cold at the surface, we have many reasons for believing that the interior of the earth is highly heated. Proof of this is found in the facts that at the surface, volcanoes emit quantities of molten rock which come from below, and that in all deep mines and well-borings the temperature of the rocks is found to increase at a moderately uniform rate, on the average 1° for about every 50 or 60 feet of descent. If this rate of increase continues, the rocks at a depth of less than 100 miles are so hot that they would be molten under the conditions which exist at the surface.

It was once believed that the interior of the earth was in a molten condition, and that the solid surface was merely a crust resting upon this liquid sphere; but many facts now lead us to the belief that the interior is at least as rigid as steel. The proof of this is mainly astronomical, and cannot be adequately stated here. At present we are forced to the belief, that although highly heated, the rocks in the interior of the earth are prevented from melting by the great pressure of the overlying layers; and by this theory we are able to satisfactorily account for all of the phenomena that

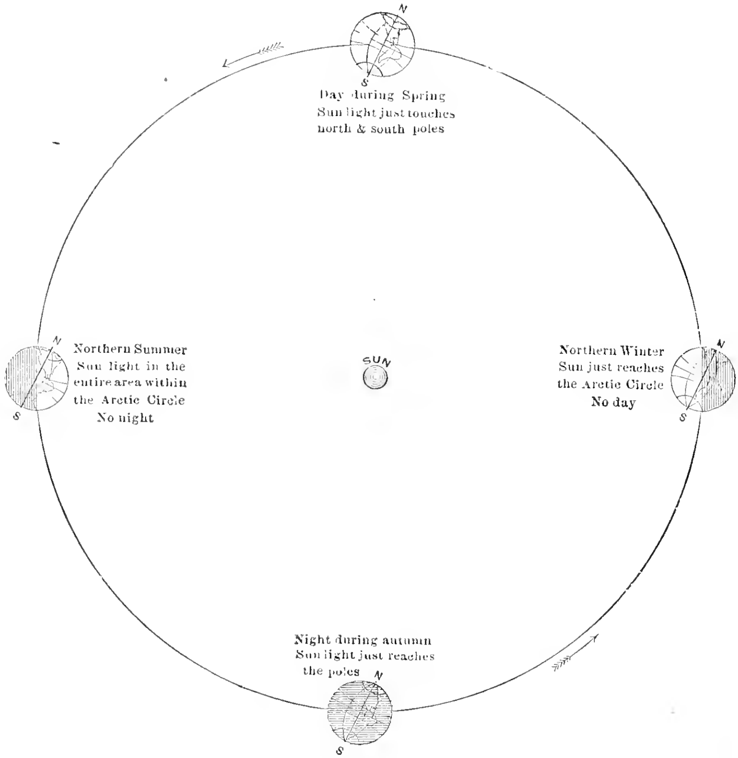

FIG. 8.

Diagram illustrating the cause of seasons.

formerly seemed to demand the explanation of a liquid interior.

The earth is engaged in a number of movements in space. It revolves around the sun in 365 days and 26 minutes, in an orbit which is nearly a circle; but instead of being actually a circle with the sun at its center, the orbit is really an ellipse with the sun at one of the foci. Therefore, in the course of its revolution, the earth is at one time farther from the sun than in the opposite season, the distance now varying between 91,000,000 and 94,000,000 miles, with an average distance of about 92,750,000 miles.

During the revolution, the earth rotates about one of its diameters, which we call the *axis*, and this rotation occupies a little less than 24 hours (23 h. 56 m.), or one day. This rotation causes the familiar alternation of day and night; and if the earth's axis were at right angles to the plane of revolution, the day and night would be equal in length; but since it is inclined to this plane at an angle of 23° 27′, the relative length of day and night varies from day to day. Indeed, the seasons themselves depend upon this inclination of the poles (Fig. 8); for in the course of a revolution, the pole is always pointed toward a certain part of the heavens; and as the earth moves about the sun, the northern hemisphere alternately faces and is turned away from the sun. When turned toward the sun, the summer season is caused, and when turned away from it, the winter season results, because the solar rays then fall less vertically upon the hemisphere, and the length of the day is shorter. Between these two opposite seasons we have spring and autumn.

The Moon.—This, the nearest to our earth of all the heavenly bodies, has an average distance of about 240,000 miles, and a diameter of 2160 miles (Fig. 9). Since the path of the moon about the earth is an ellipse with the earth at one of the foci, the distance varies; but it is rarely more than 253,000 miles nor less than 227,000 miles distant. When farthest from the earth it is said to be in Apogee, and when nearest in Perigee; and once in every revolution Apogee and Perigee are reached.

Aside from those it makes in company with the earth, its two important movements in space are a revolution around the earth and a rotation about an axis, both of these movements occurring in the same period of time, or $29\frac{1}{2}$ days. Therefore one side of the moon is never seen from the earth. Also, as a result of this condition, the length of the lunar day is $29\frac{1}{2}$ of our days; and therefore at the lunar equator the sun shines steadily for nearly 15 days and is absent an equal length of time. Under these conditions the surface of the moon is warmed during the long day, and at night becomes cooled down to temperatures which are perhaps as low as − 200°.

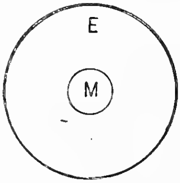

FIG. 9.
The relative size of earth and moon.

There is no atmosphere and no ocean on the moon; and the only change upon the surface seems to be that between conditions of heat and cold, and light and darkness. It does not emit a perceptible amount of radiant energy, and the light from the moon is reflected sunlight.[1] As a result of the careful telescopic study of the moon,

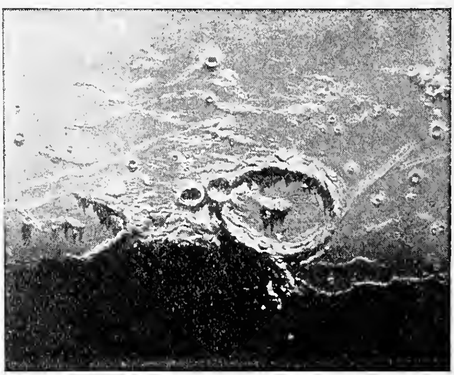

FIG. 10.
Lunar craters, the largest being Gassendi.

[1] Direct light from the sun is 600,000 times as strong as that which is reflected from the moon.

astronomers have been able to map many of the details of lunar topography, with considerable accuracy, and even to measure mountain heights. While there are other striking topographic features, the most notable thing about the lunar landscape is the gréat number of crater-like mountains, which bear a certain resemblance to the volcanoes on the earth's surface, excepting that many of them are of immense size (Fig. 10).

Comets, Shooting Stars and Meteors. — Aside from those described, which may be considered the *normal* members of the solar system, there are other heavenly bodies which do not appear to be *regular* parts of the system. The strangest of these are *comets*. Some 500 of these have been recorded as visible to the naked eye; and in addition, over 200 have been detected by the aid of the telescope, some of these being millions of miles in length. When near the sun, they usually have a relatively dense head and a vaporous tail, through which stars are visible (Fig. 11). Some have regular elliptical orbits, and their time of appearance can be closely calculated; but the orbits of others are *apparently* parabolas, so that if they ever return to the solar system, it is only after long periods of time have elapsed, and after having made a journey far beyond the outermost limits of the solar system. Perhaps these may be mere wanderers through space, which after one visit to the solar system, depart never to return again. What they are, whence they came, whither they are going, or what relation they bear to the solar system, is still an unsolved mystery.

Fig. 11.
Coet of Donati, 1858.

Comets have an added interest to us, from the fact that some *shooting stars* and *meteors* seem to be remnants of comets, which at some former time have crossed the orbit of the earth. Thus the November meteorites are due to the fact that in its movement around the sun the earth encounters particles that are left in the trail of a comet (Tempel's) which has a period of revolution of about thirty-three years; and the August meteors (Fig. 12) appear to have a similar origin.

Meteors and shooting stars (meteors are large shooting stars) enter the earth's atmosphere at a high rate of speed, and are burned up in the higher layers of the atmosphere, often at an elevation as great as 100 miles from the surface of the earth. This burning is the result of friction with the air, which produces a high heat, because in addition to the movement of the meteor, there is often added the motion of the earth itself, which is about 98,000 feet a second. Hence in small bodies, the burning is almost instantaneous; but some of the larger meteors pass entirely through the atmosphere, and reach the earth's surface.

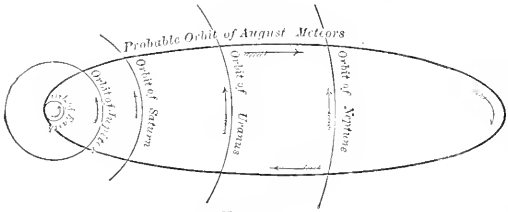

FIG. 12.
Orbit of the second comet of 1862.

A study of these rather rare meteorites, reveals to us the very interesting fact that no new element exists in them; and therefore we may fairly conclude that the elements composing comets are the same as some of those which make up the earth's crust. In watching the heavens at night, scarcely an hour can pass without noticing shooting stars; and since the same would probably be true of the day if we could then see them, we conclude that there are immense numbers of these bodies in the space through which the earth travels.

The Stellar System. — Far away in space, many times farther than the sun is from us, innumerable stars are scattered. Already many thousands are known, and it is estimated that over 30,000,000 are visible with the telescope. Like the sun, they emit an energy which produces both light and heat; and it is very probable that many, if not all, have planetary bodies revolving about them. One satellite, that belonging to Sirius, has already been discovered; and some double stars are known to be revolving about a common center of gravity. The distance between the stars, and even between the earth and the nearest stars, is immense, and in most cases incalculable. If each star is a sun with accompanying planets, and if each of these suns is as far from its nearest stellar neighbors as we are from ours, the immensity and grandeur of the system transcends our imagination.

FIG. 13.
Ardromeda nebula, from a drawing.

The stars are arranged in a disc-like belt, the greatest diameter of which is in the direction of the Milky Way. At right angles to this there is a zone of abundant *nebulæ*, (Fig. 13), although these strange bodies are not absent from other parts of the heavens. Some have conjectured that nebulæ are other stellar systems, so distant from us that the individual members cannot be separated by our telescopes; but the spectroscope seems to show that they are bodies of glowing gas, and this has an important bearing upon the nebular hypothesis, which we soon discuss. One very important thing concerning both stars and nebulæ, is that the spectroscope has detected in them many of the elements which we find upon the earth.

A question of very deep interest, is whether the stars form a great system in which the individual members are interrelated, as is the case among the members of the solar system? Unfortunately, in the present state of science, we are unable to return a definite answer to this question.

Symmetry of the Solar System.—In theorizing upon a basis of known facts we must confine ourselves to the solar system; and it is interesting to note the wonderful symmetry of arrangement and the beautiful order which exists here. Throughout the entire system, the law of gravitation prevails and governs the movements of all the bodies, each member attracting the other in direct proportion to the product of the masses and inversely proportional to the square of the distance. The regular members of the system are all nearly spherical, and they rotate about an axis and revolve in an orbit which is nearly circular. In direction of rotation and revolution there is a marked uniformity, as there is also in the plane of revolution.

All of these regularities of behavior, take place notwithstanding the fact that immense distances separate the various bodies, and that this space is practically void. We can form no accurate conception of these immense distances; but the following quotation from Newcomb's Astronomy furnishes some idea of this:—

"To give an idea of the relative distances, suppose a voyager through the celestial spaces could travel from the sun to the outermost planet of our system in twenty-four hours. So enormous would be his velocity, that it would carry him across the Atlantic Ocean, from New York to Liverpool, in less than a tenth of a second of the clock. Starting from the sun with this velocity, he would cross the orbits of the inner planets in rapid succession, and the outer ones more slowly, until, at the end of a single day, he would reach the confines of our system, crossing the orbit of Neptune. But, though he passed eight planets the first day, he would pass none the next, for he would have to journey eighteen or twenty years, without diminution of speed, before he would reach the nearest star, and would then have to continue his journey as far again before he could reach another. All the planets of our system would have vanished in the distance, in the course of the first three days, and the sun would be but an insignificant star in the firmament.

The sun in the center of the solar system is a true star, in many respects like the others which dot the firmament. This being the case, may we not fairly speculate as to the possibility of other worlds and systems like our own, far away in space, even to the outermost limits which can be reached by the human vision; and if this be so, how vast is the universe, and how insignificant the small cold body of matter upon which we dwell!

The Nebular Hypothesis. — Before many facts concerning the universe were known, the philosopher Kant proposed a hypothesis to account for the origin of the solar system; and later, Herschel and Laplace proposed an explanation which in many respects was like that of Kant. We know this explanation under the name of the nebular hypothesis.

By this it is assumed that the space occupied by the members of the solar system, and probably even to a considerable distance beyond this, was occupied by a nebulous mass of highly heated vapor. It is one of the laws of nature that radiant energy passes from warmer to colder bodies, and that by this radiation a contraction and condensation necessarily follow. This nebulous mass, composed of all the elements which now enter into the composition of the various members of the solar system, during the process of cooling separated into rings which were the parents of the several planets. As the mass lost heat and began to condense and contract, the materials began to accumulate about some denser part of these rings, the accumulations about these denser portions being determined by the fact that gravitative action was stronger there than elsewhere.

As a result of this accumulation about centers, the original nebulous mass became broken up into several smaller masses of similar nature; and by a continuation of the process other rings were thrown off, out of which the satellites were formed. Original motion about a central portion of the nebula has naturally been inherited and is now indicated by the movements of the bodies in the solar system. The cooling of these bodies is still in progress, and different members of the system have reached different stages.

Verification of the Nebular Hypothesis. — While we cannot state that this theory is definitely proven, many facts point to its truth as a general explanation of the solar universe. For instance, it would account for the fact that the planets move about the sun in a common direction, and that the planes of revolution are nearly the same in the different planets (the inclination in no case being more than a few degrees). This similarity also extends even to the satellites; and the rotation of the bodies whose rotation has been determined has the same kind of uniformity. All of the orbits of the members of the solar system are ellipses approaching a circle. This together with the uniform action of gravitation suggests a common origin.

The fact that all the bodies regularly belonging to the solar system are nearly spherical in form is suggestive; and this form can readily be accounted for if the bodies were once liquid. A former liquid condition is indicated by the fact that those bodies which are well known, all have a larger diameter at the equator than at the poles; and this is what would result from centrifugal action in a liquid sphere. Then also, signs of heat are plainly seen in some of the members of the solar system; and in the smaller bodies these signs are less apparent. Thus the sun is highly heated; Jupiter, Saturn, and other of the outer planets show signs of considerable heat; the earth is cold at the surface, and hot in the center; Mars, Venus, and Mercury are cold at the surface; and the moon appears to be entirely cold.

Upon the nebular hypothesis, we should expect that the density of the members of the solar system would increase from the outer bodies toward the center; and this actually is the case, the only exceptions being the easily explained cases of Saturn and the sun. There are other reasons for believing in the nebular hypothesis. So far as we may judge from the results of spectroscopic study and from the examinations of meteorites that have fallen upon the earth, the bodies in the solar system are composed of the same elements as those which make the earth; and this suggests that they have been made from the same original mass.

Far away in space, beyond the solar system, we even find nebulous masses of gas which are exactly like those out of which the solar system is believed to have been made; and in some of these nebulæ the condensation into planetary bodies appears to be in progress (Fig. 13). Nearly every gradation has been found between this kind of nebula and that which is apparently one mass of glowing gas. It is not improbable that even now other worlds are in process of formation in the far distant regions of space.

REFERENCE BOOKS.[1]

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Scheiner (translated by Frost). — A TREATISE ON ASTRONOMICAL SPECTROSCOPY. Ginn & Co., Boston, 1894. 8vo. $5.00.

[1] In giving the publisher's name, the real publishing house is often not mentioned. Wherever possible American houses are given, and since some of these act as agents for European houses, the name of the *agent* will at times appear in the place of the English publisher.

CHAPTER II.

THE ATMOSPHERE.

General Statement. — Outside of the solid earth, and extending to a distance of several hundred miles above it, is a gaseous envelope, which we know as the atmosphere (Fig. 14). Its density decreases from the surface of the earth toward the upper portions; and at a height of five miles it is very much rarefied. That it extends to this great height is shown by the fact that meteors become white hot by friction with it, even at a greater distance than this from the earth. Fully one-half of the mass of the atmosphere is within four miles of the surface of the earth; and two-thirds of it is within six miles of the surface (Fig. 15).

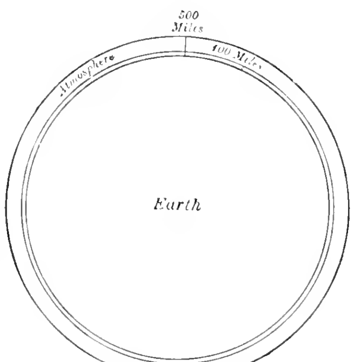

FIG. 14.
The earth with its atmospheric envelope, drawn to scale.

The atmosphere is composed almost entirely of two gases, nitrogen and oxygen, in the proportion of about 79 to 21. These gases are not in chemical combination, but are mechanically mixed. *Nitrogen* is a very inert element, while *oxygen* is active in the production of many changes, and from this standpoint the nitrogen of the air may be considered as an adulterant of the active oxygen. In addition to these gases there is a comparatively small amount (about 0.03 per cent) of *carbonic acid* gas, the percentage varying somewhat according to the location. Its percentage increases in the vicinity of volcanoes and large cities.[1]

Beside these three gases there are minor and variable quantities of other substances; but of these, only two, water vapor and dust particles, are of sufficient general importance for consideration here. The term "*dust*" includes a great

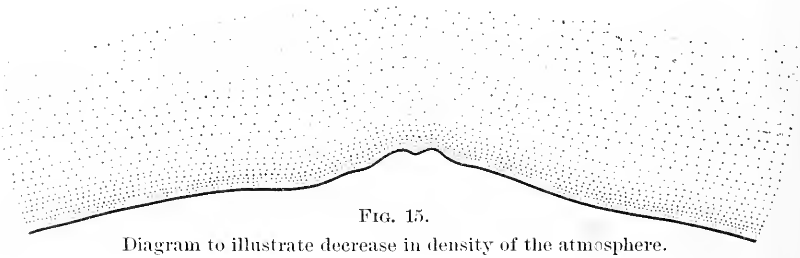

Fig. 15.
Diagram to illustrate decrease in density of the atmosphere.

variety of substances, such, for instance, as microbes, smoke particles, and true dust, which is borne into the air by the winds. It seems certain that dust is of much importance in the formation of rain and fog.

Water is readily evaporated, and hence at all times there is some *water vapor* in the air; but the amount depends upon a variety of circumstances, chiefly the temperature of the air and the presence or absence of bodies of water. The higher

[1] While this book is in preparation, the discovery of a new constituent of the atmosphere is announced. This, which is called argon, may be a new element, but it is now too early to state anything definite about this substance.

the temperature, the greater the rate of evaporation; but even at temperatures below freezing-point small quantities of water vapor may be present.

The atmosphere is of great importance in many respects. It distributes the light which comes to us from the sun. It is set in motion by the solar energy, and by this means distributes heat over the earth. As a result of the effect of solar heat upon the atmosphere a great variety of phenomena, such as winds, storms, clouds, etc., are produced. These cause many changes upon the surface of the earth, and directly and indirectly the air makes the earth a place fit for habitation.

Light. — We obtain light from several sources, — the sun, the stars, and the moon and planets. Light from the latter source is merely reflected sunlight, and it is small in amount. That which comes from the stars is radiated from them directly, but it also is insignificant in comparison with that received from the sun.

Solar light, when it reaches the lower layers of the atmosphere, produces the impression upon the eye which we know as white; but there is reason to think that it has a bluish tinge before its passage through the air. According to the undulatory theory, light passes through the space between us and the sun at a very rapid rate in the form of a series of waves of ether. It is made up of many waves of different lengths, the combination of which gives white. When separated, these appear as different colors, and in the rainbow we recognize seven primary colors with intermediate tints. The violets and blues have the shortest vibrations, and the yellows and reds the longest. As a result of the effect of the atmosphere upon these parts of white light many optical phenomena are produced.

If there were no atmosphere, the earth's surface would be illuminated only where the direct rays of the sun fell. The atmosphere serves to diffuse light and to render the darkness of shadows less intense. This *diffusion of light* in large measure depends upon the amount of solid or liquid impurities in the air. In its passage through the air, certain of the rays are diffused more readily than others by the process of *selective scattering*. It is usually those with the shortest wave lengths that are thus scattered; and hence it is that the sky is ordinarily blue. The intensity of the blue is greatest when dust impurities are least abundant, as is the case when the air is clear and dry. If dust particles happen to be very abundant, even the coarser rays of yellow light may be scattered ; and under rare conditions of very smoky air the entire sky may assume a brassy color. Since the light is obliged to travel through a greater distance of air near the time of sunset than in midday, the color of the western sky in the late afternoon is often yellow, while that of midday was a dull hazy blue (Fig. 16).

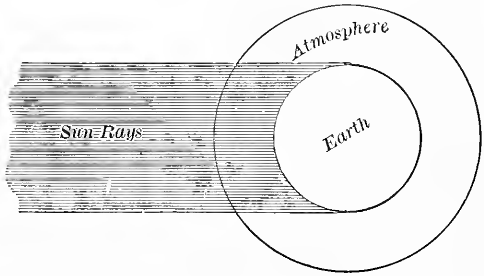

FIG. 16.

Diagram to show that the sun's rays pass through a greater thickness of atmosphere at sunset and sunrise than at midday. (Thickness of atmosphere greatly exaggerated).

Among the most beautiful of light effects in the atmosphere is that of the *sunset colors*, which are due to the scattering of the waves which have the smaller lengths. As a result of this the coarser yellows and reds come to us, the reason for the scattering being the fact that the light at the time of sunset and sunrise passes through a great thickness of air, and hence the waves encounter a greater number of dust particles. When the atmosphere contains much dust, the morning and evening colors are often very intense, but an increase in the quantity of dust beyond a certain point tends to dull the tints. With clouds in the horizon at sunset or sunrise, these colors of red and yellow are often reflected in infinite variety of shade and tint. Other phenomena, such as the twilight arch, the glow and the afterglow, are not easily explained in a few words.

Another property of light is that of *reflection*, and as a result of this many interesting optical effects are produced. The light of the moon depends upon the reflection of sunlight from its surface. The earth also reflects light, and this is one of the reasons for the illumination of places that are in the shadow of the direct rays of the sun. Other places which are illuminated reflect some of their light to the parts that are in shadow. Clouds also reflect the light of the sun; and on summer days, when great banks of clouds rise high in the air, their surfaces are brilliantly illuminated and beautiful cloud effects are produced.

Another effect of reflection is the *mirage*, which occurs when the air near the surface is warmer than the layers above it, and when the reflection from this warm air layer reaches the eye of the observer. It often gives rise to an appearance like that of a sheet of water; and travelers in desert lands, where this phenomenon is common, are often led to think that they are actually approaching a lake. One very commonly sees such an appearance as this at the sea or lake shore when distant coasts appear to rise above the surface of the water. It sometimes happens that light is reflected from a warm layer which is above the observer; and then the objects appear upside down. This "looming," as it is called, is particularly common in Arctic regions; and the effect produced is so fantastic and wonderful that nearly all Arctic explorers describe it.

The rainbow is a phenomenon which partly depends upon the reflection of sunlight; but it is chiefly due to *refraction*, the result being a separation of the several components of white light into the colors of the spectrum. Each person sees a different rainbow even though two observers may stand side by side. The cause for the phenomenon is the effect of raindrops which, being denser than the air, bend and separate the rays of white light so that we see the component colored rays, just as we do when a sunbeam passes through a prism. A rainbow is often produced in the spray that rises at the base of a waterfall, and at the distance of only a few yards one may see it outlined in the spray.

Another phenomenon resulting from the combined action of refraction and reflection is the ring of light or *halo* which often surrounds the sun or moon when their light passes through thin hazy clouds in the upper atmosphere. These clouds are composed of ice particles, which act upon the light in a manner analogous to the effect of raindrops in the production of the rainbow. Very remarkable halos are formed, particularly in Arctic regions, where the air is often filled with minute crystals of ice. Sometimes rings of light of very brilliant colors are thus produced. The interference with light resulting from the presence of water or ice in clouds often produces a ring of light immediately around the sun or moon. These are called *coronas*, and they are often beautifully colored, the colors being arranged in concentric rings with the red on the outside.

One of the most important of the phenomena of light is that of *absorption*. Many bodies, such as pure air and water, allow most of the rays of light to pass through them with little change, and such bodies are called *transparent*. Other substances are only partially transparent, and we know them under the name of *translucent* bodies. Still others which we know as *opaque* do not allow any light to pass. Thus objects have a red color when they reflect a greater number of the red than of the other rays; and other colors are produced in the same way by the absorption of different proportions of the rays.

Electricity and Magnetism. — There are certain phenomena of magnetism in the earth which seem to exercise a decided influence upon the atmosphere. The earth is a great magnet, and the region of greatest magnetic attraction is near Hudson's Bay, toward which the needle of the compass points in our hemisphere. This may be called the *magnetic pole*. The magnetic condition of the earth is constantly changing, both in small daily variations and in annual changes, as well as in variations covering many years. Occasionally there are magnetic storms, when there is a disturbance of magnetic instruments, and when the *aurora* sometimes develops in wonderful complexity and weird beauty. This is some electrical effect in the thin upper atmosphere; but our knowledge of these phenomena is obscure.

Electricity is produced in the atmosphere by various causes, and it is nearly always present; but only rarely does it develop sufficient intensity to become visible to the eye. In thunderstorms and tornadoes, when the air is in violent commotion, there is often sufficient electricity to cause vivid discharges from one cloud to another, or to the earth. This *lightning* is an interesting phenomenon, but it does not appear to have a marked influence upon the atmosphere. It is apparently an incident. The accompanying sound is often changed to a rumble by reverberation and echoes among the clouds, and between them and the earth. Often in violent thunderstorms the air is filled with a constant roar of *thunder*. The lightning spark or bolt is sometimes a single large spark, or it may divide and sub-divide, giving a branching type of discharge; and many interesting irregularities of direction, color, and form are produced.

The light from the flash moves with great velocity while the sound of the thunder travels slowly, at the rate of ordinary sound waves. The sound wave is readily worn out, and at a distance of a few miles lightning produces no perceptible sound. *Heat lightning* is often the result of the reflection among the clouds, or on the horizon, of lightning in some far-distant thunderstorm, perhaps entirely hidden behind the curvature of the earth.

Heat.[1] — Aside from the heat which comes to us from the sun, we obtain a certain small but more constant supply from the other bodies of space and from the earth itself; but these are relatively unimportant. The radiant energy from the sun travels at an enormous velocity as a series of waves, which are radiated out from the sun in all directions; and only that small portion of them is received by the earth which it happens to intercept in its passage about the sun.

Some substances allow this energy to pass through them with readiness, and these are said to be *diathermanous;* others *absorb* heat; and still others *reflect* the greater part of the rays that come to them. The air is comparatively diathermanous, as indeed most transparent substances are. The smooth glassy surface of water is a good illustration of a substance that reflects much of the radiant energy coming to it. On the other hand, while the earth reflects some, it absorbs a large quantity of heat; and this is

[1] The sun is emitting a form of energy which under favorable conditions becomes heat, while under other conditions it takes the form of chemical energy. These rays are therefore properly radiant energy until transformed to heat.

particularly true for parts of the earth which are dark in color.

The rays that enter the atmosphere pass through it with little interference, because it is diathermanous; but if there is much dust or water vapor in it, a considerable share of the rays are intercepted. Thus clouds effectually check the passage of many of the rays, and therefore cloudy days are cool. The same tendency exists when the atmosphere is very hazy; and in the late afternoon when the solar rays pass through a great thickness of air (Fig. 16), the amount of heat that reaches the earth is very much less than that which comes to the surface at midday.

Since different parts of the earth's surface behave differently toward the radiant energy, there is much variation in the effect produced. This is particularly well illustrated by the very marked difference in behavior between water and land. The rays that reach the water surface are in part reflected back into space and thus lost, so far as the earth is concerned. Much of that which remains raises the temperature of the water; but as the specific heat of the water is high, its temperature is raised very slowly. Some is used in the evaporation of the surface layers; and in that case the heat is transformed to the so-called "latent heat,"[1] which does not become apparent until the vapor is condensed to water. Moreover, the water surface is in motion; and this tends to distribute the heat, and thus to prevent the excessive warming of the ocean surface. Therefore for these various reasons, even at the equator the ocean surface remains relatively cool.

On the other hand, land reflects very little of the radiant energy, and it is a solid body, in which neither evaporation

[1] The old term is still used, though perhaps heat of vaporization would be better.

nor motion is possible. The earth is distinctly not diathermanous, and the greater part of the rays which reach it are absorbed by the surface portions. Therefore during the day the ground tends to become warmed by absorption; and this peculiarity is responsible for many of the phenomena of the atmosphere.

Pure air is very slightly warmed by the passage of the direct rays of the sun. The small amount of heat thus obtained is slightly increased by a supply received from the rays which the earth reflects; but much more is obtained from the supply which the earth absorbs. All bodies in space are radiating a form of energy, either that which belongs to them or that which is radiated to them; therefore the earth is at all times emitting rays by *direct radiation.* During the daytime the amount radiated is less in quantity than that received from the sun; but at night, when this supply is cut off, the process of radiation proceeds so far that the earth loses much of the heat which it had received. Radiation is interfered with by the presence of clouds or dust; and hence nights which are cloudy or hazy are warmer than those which are clear.

By the process of *conduction*, all bodies which are warmed tend to transmit their energy to cooler portions. This is well illustrated when a cold iron is placed upon a warm stove. In the same way, the air in contact with the warmer earth is thus warmed by conduction; but neither air nor earth are good conductors of heat, and if this process were unaided, the effect would be slight and confined to those lower layers of the air which were almost immediately in contact with the earth. It is a property of gases that when heated they are expanded and thus caused to move. By this means a process of *convection* is started which is analogous to the boiling of water, and the warm lower layers of air rise above the surface, their places being taken by other layers which flow in toward the point of ascent.

This process of convection is one of the most important in meteorology; for upon it in large measure depends the formation of the winds and other features of atmospheric circulation. When air rises it expands, and in the process of expansion cools dynamically, the rate of cooling being 1.6° for every 300 feet of ascent; and descending air, as a result of compression, tends to warm. This feature of cooling on ascension gives rise to the formation of many of the clouds and rainstorms.

Thus the air is warmed, partly by the rays which come direct from the sun; partly by those which are reflected from the earth; partly by those emitted from the earth by the process of radiation; but mainly by conduction from the warm earth's surface and the convectional rising of these warmed layers. Highlands are cooler than lowlands, largely because the air in these places is less dense than that nearer the sea level (Fig. 15). The presence or absence of large bodies of water very markedly modifies the effect of solar energy upon the atmosphere. As a result of these differences, the atmosphere is put in motion, winds are produced, clouds are formed, storms are started, and rains are caused.

The movements of the earth in space also give rise to many variations in heat effect and atmospheric phenomena. As a result of the rotation of the earth, the greater part of its surface is lighted and warmed once every twenty-four hours, and cooled once during that time.

A second important movement of the earth is that of revolution, which causes the seasons (Figs. 8 and 17). Since the pole is inclined to the plane of revolution, the sun is made to appear to migrate in the heavens. During our winter, when the sun is vertical over that part of the earth which lies between the equator and the tropic of Capricorn, the sun rises in the southern part of the heavens, and passes westward without rising high toward the zenith. Then in Arctic latitudes, the sun does not rise above the horizon; and therefore in this region there is no alternation of day and night. In the winter season, in temperate

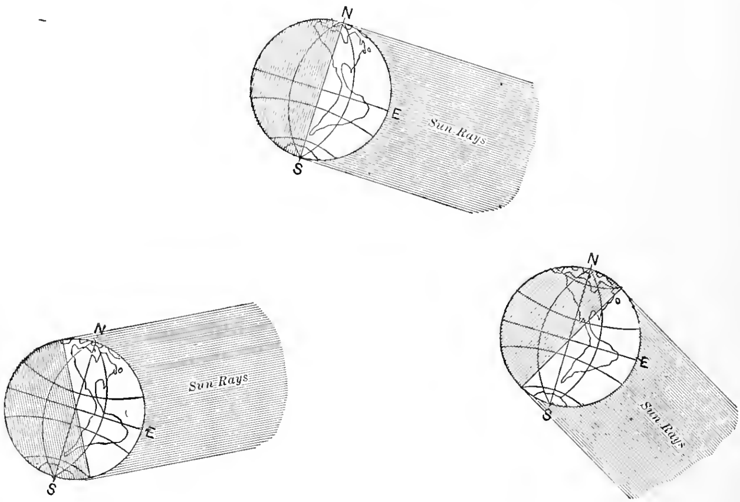

Fig. 17.

Diagram to show the inclination of the sun's rays in different parts of the earth during the various seasons. Upper figure, spring and autumn; right-hand figure, northern winter; left-hand, northern summer.

latitudes the journey of the sun across the heavens occupies a small fraction of the whole day; and therefore in such regions the time during which the earth is receiving heat is less than the length of the night, during which almost none is received.

Besides this fact of short days and long nights, the angle at which the rays reach the surface is much more oblique than in the summer season; and before reaching the surface they are obliged to pass through a great thickness of atmosphere. These facts make the effect of the small amount of energy that does come, less apparent in winter than in summer, when many of the rays pass from a point near the zenith through a relatively small amount of atmosphere, reaching the surface more nearly at right angles (Fig. 17). After the sun has passed north of the equator, summer comes to the northern hemisphere, while winter prevails south of the equator.

Thus at any point between equatorial and Arctic regions, there are two variations in the effect of the solar rays, one a daily and the other a seasonal variation. The temperature of the air over the land normally rises during the day, and falls at night; it rises in summer, and falls in winter; and the amount of daily rising and falling is greater in winter than in summer. There is much variation in these respects according to latitude; and there is less change in temperature between day and night, and between seasons, at the equator than in other latitudes; but the *amount* of heat received there is greater than in other parts of the earth. The greatest range in temperature, both seasonal and daily, is experienced near the Arctic circle. The least heat supply is received in polar latitudes; and here there is a great range between the summer and winter temperatures, but slight daily ranges, because in winter the sun does not rise above the horizon, while in summer it does not set.

Moisture. — When rays of radiant energy enter a water body, they are in part transformed to "latent heat," being engaged in the process of changing the liquid to a gaseous condition. By this process of *evaporation* much of the energy exists in a form which is not apparent as heat so long as the vapor condition lasts; but when the vapor is condensed, this store of heat becomes apparent. Evaporation will take place even from a snow surface; but the most favorable conditions for the production of water vapor are warm air in contact with a water surface.

The capacity of the air for water vapor is limited; and when no more can be contained it is said to be *saturated.* An air in which there is little vapor is constantly capable of taking more until the limit of saturation is reached. We commonly say that dry air can *absorb* vapor.[1] If the amount of water upon the land is slight, the air in these places remains dry; but naturally this cannot be the case with air over bodies of water, for there the conditions favor saturation. In the interior of continents, and in the upper layers of the atmosphere, there is the smallest proportion of water vapor. If the air from these places reaches the oceans, it may bring to them conditions of dryness, which, however, are soon changed to relative dampness. With the air in movement, saturation is less liable to occur than would be the case if the air were quiet. Therefore winds favor evaporation by bringing fresh supplies of air, and for the same reason they tend to prevent saturation.

The capacity of air for water vapor also depends upon its temperature. A layer of air which is saturated at the temperature of 50° becomes relatively dry if its temperature is raised to 90°; and an air layer which is nearly saturated at 90° will be obliged to give up some of its water vapor if the temperature is lowered a number of degrees. This is a very important point in the formation of clouds, storms, and rains. The *actual amount* of water vapor in the air represents its

[1] Strictly the air does not absorb vapor, but the water vaporizes regardless of the presence of the air. However, it is convenient to speak of the capacity of the air for water vapor, especially as the air determines the temperature.

absolute humidity; but this is not a very important factor, because the same amount of vapor in air of different temperatures will produce very different effects.

The point of greatest importance is the *relative humidity*, which is the percentage of water vapor *actually* contained in the air compared with the amount which the air at that temperature *could* contain if it were saturated. Thus the relative humidity of saturated air at a temperature of 60° is 100 per

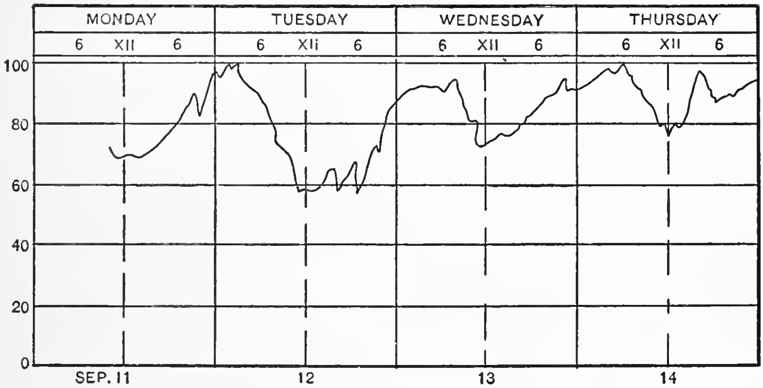

Fig. 18.

Diagram showing daily change in relative humidity as a result of the daily change in temperature at Ithaca, N.Y.

cent, for at that temperature no more can be contained; but if the temperature is raised a few degrees, the air becomes capable of containing more water vapor, and the relative humidity is then less than 100 per cent. The temperature at which air becomes saturated is known as the *dew point*, for then vapor must be condensed. After a warm and apparently dry day, dew may be formed at night merely by lowering the temperature of the air, and thus increasing the relative humidity, without any change whatsoever in the absolute humidity (Fig. 18).

It follows from this that there must be very marked differences in the amount and effect of water vapor contained in the air. Over the oceans, the relative humidity is great, and the air nearly always near the point of saturation; in the tropics, where the temperature is high, the absolute humidity is high, because warm air can contain much vapor; and on mountain peaks, where the temperature is low, the amount of vapor is slight, because cold air has little capacity for water vapor. If the dry upper air descends to the earth, its absolute humidity is low; and even if it commenced its descent in a saturated condition, its relative humidity decreases because the temperature rises (Fig. 19); and if air currents move from cooler to warmer latitudes, their capacity for vapor is constantly increasing, because they grow constantly warmer and have a greater power of absorbing vapor. When they move from warm to cooler regions their relative humidity increases, because their temperature descends; and when air rises over land elevations, or vertically by convection, the relative humidity is also increased, because it cools by expansion as it ascends; and under such conditions the vapor is often condensed in clouds and rain.

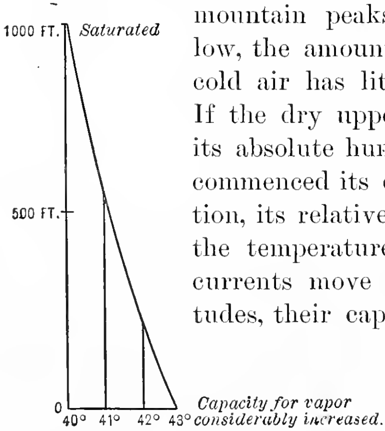

FIG. 19.

Diagram illustrating increase in temperature of descending air. Starting in a saturated condition with a temperature of 40° at 1000 feet, it reaches the surface with a higher temperature and its capacity for vapor increased, while its relative humidity has decreased. The reverse takes place with ascent.

As a result of these varying conditions we get many variable phenomena. Where the winds are prevailingly dry, and the relative humidity low, desert conditions result; and where moist winds rise over rapidly ascending lands, conditions of excessive rainfall are produced. With air prevailingly dry, evaporation is rapid, while in regions of great relative humidity, evaporation is slow and small in amount (Fig. 60). Since water vapor contains a store of "latent heat" great stores of heat energy are transported from one latitude to another by the movements of vapor-laden air currents.

Pressure. — The air, though so light and apparently almost without substance, actually has weight. At the seashore, the average weight of the air column is 15 pounds to the square inch; but as we ascend into the air, whether in a balloon or on a mountain, the pressure of the air becomes less and less. Aside from this difference in air pressure the weight of the column of atmosphere at any single point is almost constantly changing. This is due to the fact that the air is very elastic and is subjected to a complicated series of movements. We shall be better able to understand the causes for these changes in pressure, and their effects upon the atmosphere, after we have examined in more detail the subjects of air temperatures and circulation.

Effect of Gravity. — Heat is constantly tending to drive the air from the earth's surface, and therefore to make the lower layers less dense; but opposed to this is the tendency of gravity to draw the atmosphere down to the earth. The effect of this is to make the lower layers of the atmosphere more dense than those above the earth's surface; but the circulation of the air somewhat modifies this effect. Gravity is a very important factor in determining the equilibrium of the atmosphere; for its constant tendency is to restore an equilibrium which other causes are tending to destroy.

Effect of the Earth's Rotation. — As the air moves in the form of winds or currents, there is a constant tendency to be deflected to one side, as a result of the effect of the earth's rotation. This not only tends to turn the currents of air, but its influence is also felt in the ocean currents. In the southern hemisphere the currents are deflected toward the left, and in the northern hemisphere toward the right; and we commonly speak of the latter as the right-hand deflection (Fig. 20).

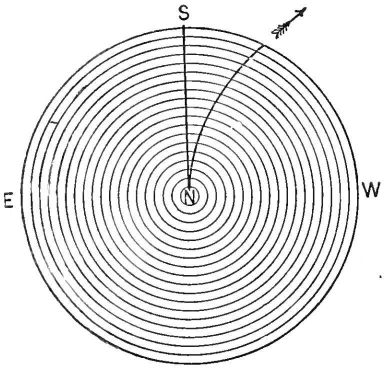

Fig. 20.

Diagram to show how the moving currents are deflected from a straight line N-S.

The reason for this deflective tendency is to be found in the fact that different parts of the earth are moving at different velocities. By revolving an orange or a ball around an axis one can see that the motion at the equator is much more rapid than that at the poles. Each revolution carries every point along a circle, but the diameter of the circle decreases toward the pole (Fig. 21). Therefore in the course of a revolution a point near the equator travels a much greater distance than one near the pole. To do this, it must go faster, since the same period of time is allowed. At the equator the rate is 1521 feet a second, while near the poles the rate is greatly reduced.

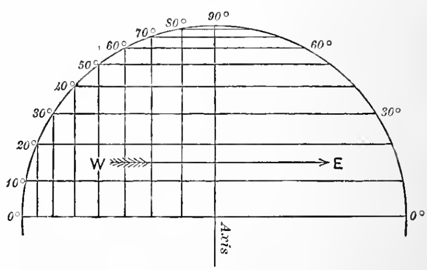

Fig. 21.

Diagram illustrating the decrease in diameter on different latitudes.

A current moving toward the equator, from a region of slow motion, is constantly reaching latitudes where the angular velocity is greater. If the earth were quiet, it would move in a straight line, and if the earth's rotation did not produce any effect, it would do the same and reach a point on the equator toward which it had originally started (N–S, Fig. 20). But the earth is rotating toward the east, and the current is of course carried along; but in different parts of its course it is carried at different rates. There are therefore two motions, one to the south, the other to the east. As the current in its southerly course reaches regions with a greater velocity than those just left, it lags behind the earth's rotation just a very little. In other words, it tends to take to regions of greater velocity the velocity of a region with a slower motion. This lagging behind turns it to the west, or the right, and as it moves from place to place (Fig. 20) it keeps turning little by little, until finally its course is very much altered. Currents moving northward from the equator pass into regions of less velocity and thus run ahead, or turn to the east in the direction of the earth's rotation. The same explanation holds for the left-hand deflection south of the equator.[1]

A current moving very slowly will so nearly accommodate itself to the change in velocity that the deflective tendency is not very effective. Also in those latitudes, such as the equatorial (Fig. 21), where the difference in velocity is not great, the deflective tendency is not nearly so great as in the higher latitudes, where even in a small distance there is a marked difference in angular velocity.

Even in currents moving along east and west lines the

[1] The teacher will do well to illustrate this important point by the use of the globe, or better by allowing a marble to run over the face of a rapidly revolving wheel which is inclined toward the class.

deflective effect is apparent, but this cannot be easily explained in a few words.

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